Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Phone: (508) 548-1400
Telex: 951679

1930

June 10, 1994

Dr. Lou Goodman
Office of Naval Research
Small Scale Physical Oceanography (Code 322PO)

Dr. Steve Ramp
Office of Naval Research
Meso to Large Scale Physical Oceanography (Code322PO)
Ballston Tower 1
800 N. Quincy
Arlington, Virginia 22217-5000

Dear Lou and Steve:

This is a Final Report on Contract N00014-90-J-1470, entitled The Role of Horizontal Variability in Air-Sea Interaction, which covered our participation in the Frontal Air-Sea Interaction Experiment (FASINEX) as well as our administration and coordination of that program.

The cooperative Frontal Air-Sea Interaction Experiment (FASINEX) was conducted in the subtropical convergence zone southwest of Bermuda from January to June 1986. The overall objective of the program was to investigate air-sea coupling in the vicinity of horizontal gradients associated with ocean fronts. The FASINEX field experiment was very successful and resulted in a rich and unique data set. The first goal of the analysis phase that followed the field work was a synthesis of results from all participants; this was accomplished by the preparation of a monograph consisting of multi-authored papers. The monograph was published in 1991. More highly focused scientific publication has continued since the monograph. The FASINEX data set is highly requested. We have distributed it,

and papers by investigators not originally involved in the field experiment are now being published.

FASINEX: The objectives and field work

The basic objective of FASINEX (Stage and Weller 1985, 1986) was to make progress in understanding the role of horizontal variability in air-sea interaction. The field phase of FASINEX was conducted in the subtropical convergence zone southwest of Bermuda from January to June of 1986. Strong horizontal gradients were found during the experiment as a number of oceanic fronts moved through the region from the southeast to the northwest, and the FASINEX investigators using research aircraft, ships, moorings, and satellites were successful in collecting the data they needed to address the scientific issues associated with horizontal variability.

Because of the success of all parts of the field program, the close ties between various components, and the unique nature of the data, the FASINEX investigators agreed that joint analysis and publication should have a high priority. To facilitate cooperative efforts a number of workshops and meetings were held. By the time of the February, 1988 American Meteorological Society Seventh Conference on Ocean-Atmosphere Interaction, early results were available, and the investigators agreed on a Table of Contents for a monograph volume that would serve as the vehicle to bring together a series of multi-author papers that together would encompass all of FASINEX. This monograph is scheduled was published completed in 1991.

Our participation in FASINEX

Our participation in FASINEX involved an array of five surface moorings in place from January to June, 1986 and work from ships in January, February to March, and June, 1986. The foci of our efforts following the field work were basic analyses of the data sets from the moored array and shipboard activities, preparation of the several chapters of the monograph for which we are either lead author or co-authors, and administrative tasks associated with FASINEX meetings, the FASINEX Bulletin, and the FASINEX monograph.

Basic descriptive and data quality tasks were completed in late 1988 when we published the last of three data reports (Pennington and Weller, 1986a; Pennington and Weller, 1986b; and Pennington, Weller, and Brink, 1988) and two manuscripts (Weller et al, 1990a, b) detailing both our methods and examining in detail the errors associated with oceanographic and meteorological measurements made from the moored array.

The monograph chapters (Chapter 1, Introduction and overview, Weller [1991]); Chapter 5, Ocean frontal dynamics, Eriksen, Rudnick, Weller, Pollard, and Regier [1991]); Chapter 9, Forced ocean response in the vicinity of oceanic fronts, Weller, Eriksen, Pollard, Rudnick, Oakey, Schmitt, and Toole, [1991]) were completed in 1989. They provide good summary descriptions of the structure of the velocity and temperature fields associated with the oceanic fronts. The moored array saw a number of such fronts pass through moving from southeast to northwest and maintaining a roughly southwest to northeast alignment. The passage of such strong, jet-like flows through the array provided dramatic temporal signals in horizontal gradients and in vorticity. The wind-forced response will be described in Chapter 9. Further wind-forced response analyses were reported in Rudnick and Weller (1993a). The heat budget of the frontal region was reported in Weller and Rudnick (1993b).

The FASINEX investigators met in early 1988 in Anaheim and later in early 1989 in Tallahassee. These meetings and the FASINEX Bulletin were used to drive progress on the monograph and cooperative analyses. Rudnick took on the role of technical editor of the volume and finalized arrangements with the Journal of Geophysical Research for a special edition as well as a number of separate, bound volumes consisting of just the monograph chapters. Additional copies of the bound volume are available if ONR needs them.

1991 was the final year of formal FASINEX activity coordinated by us. The FASINEX Bulletin ceased publication with a final issue updating the FASINEX Contribution List.

Our own analyses have continued. Sub-frontal scale variability was found in the front (small jets some few km wide) that could be masked from view with satellites by diurnal restratification. The impact of such small features acoustic propagation as well as the sound speed variability at the scale of the fronts was presented by Weller and Samelson (1990) at a conference on ocean variability and acoustic propagation at the SACLANT Undersea Research Center, La Spezia. The spatial variability of the air-sea fluxes and meteorology observed by the 5-mooring array was quantified and published in Weller et al. (1994). Our data has been pooled with that of Eriksen's and is being used by his student, Craig Lee. Rudnick moved to the University of Washington, where we supported his final analysis work on FASINEX by a subcontract (see attached). Papers by Lee and Rudnick are being

submitted. We have had a dialog with Patrice Klein and his colleagues, giving them our data, and working together to see if the near-inertial variability in the upper ocean can be successfully modeled. We anticipate continuing use of FASINEX data in our ongoing attempts to understand upper ocean dynamics. To make the data widely available we are discussing with Peter Cornillon the possibility that he could include it in his on-line archives.

Broad perspective on the outcome of FASINEX

FASINEX did much to advance our understanding of open ocean air-sea interaction and of ocean fronts. JASIN (Joint Air-Sea Interaction Experiment) 1978 had suggested (Guymer et al., 1983) that there was coupling between the ocean and atmosphere at synoptic weather and ocean eddy space and time scales; the variability in sea surface temperature was reflected in coincident variability in air-sea fluxes. FASINEX was specifically designed to test this suggestion. The basic result was that while strong sea surface temperature features did have an impact, it was more important to consider sea surface roughness effects associated with the small scale surface current variability of the ocean front. The importance is seen both in the in-situ measurements of the air-sea fluxes and the remotely-sensed measurements. The roughness effects caused real variations in fluxes larger than the stability-related effects. In addition, the surface roughness could not be accommodated by the algorithms used with scatterometers and scatterometer winds were in error near the ocean fronts.

FASINEX also resulted in major advances in our understanding of open ocean fronts. The kinematics of the fronts, that they form to the south and move northward, locking into spatial patterns that repeat through a given year were not known before FASINEX. The small scale variability within fronts was well documented during FASINEX by the moored and shipboard work. The view of a front that results is more complex than previously envisioned. It is not a simple jet with a well-defined relative vorticity field. Rather it is a convoluted jet, with eddies on 10 km scales. This results in active three-dimensional circulation on these scales. Further, FASINEX suggested that fronts could be important regions for continuing subduction of surface water. This idea was pursued by Rudnick, Luyten, and others in the Subduction Experiment. The complexity of the FASINEX front taken together with the direct observations of near-inertial and internal waves has also led

to revised thinking of how much of the spatial variability at these frequencies can be associated with wave trapping by changes in relative vorticity.

There is no other data set with moored time series of surface forcing and ocean variability on these scales. FASINEX further has the detailed spatial investigations done in both the ocean and atmosphere. This data set will continue to be a valuable resource, stimulating further analysis and publication.

Sincerely yours,

Robert A. Weller

Robert A. Weller

cc:	Scientific Officer, Code 3223 SS	(3)
	Mr. Tanner, ONR REsident Representative	(1)
	Director, NRL, Code 2627	(1)
	Defense Tech. Information Center	(4)

attach: Final report on W.H.O.I. Subcontract to D. Rudnick

References

Eriksen, C.C., R. A. Weller, D L. Rudnick, R. T. Pollard and L. A. Regier, 1991. Ocean Frontal variability in FASINEX. Journal of Geophysical Research, 96: 8569-8591.

Guymer, T. H., J. A. Businger, K. B. Katsaros, W. J. Shaw, P. K. Taylor, W. G. Large, and R. E. Payne, 1983. Transfer processes at the air-sea interface. Philos. Trans. R. Soc. London, Ser. A, 308, 253-273.

Pennington, Nancy J. and Robert A. Weller, 1986a. Summaries for FASINEX mooring cruises. Phase One: R/V Knorr 119. Phase Three: R/V Knorr 123. WHOI Technical Report 86-35.

Pennington, Nancy J. and Robert A. Weller, 1986b. Cruise Summaries for FASINEX Phase Two. R/V Oceanus Cruise 175. R/V Endeavor Cruise 141. WHOI Technical Report 86-36.

Pennington, Nancy J., Robert A. Weller, and Kenneth H. Brink, 1988. FASINEX moored current meter array data report including WHOI meteorologically instrumented surface moorings (F2-845, F4-846, F6-847, F8-848, F10-849) and WHOI long term subsurface moorings (F1-829, F12-830). WHOI Technical Report 88-63.

Rudnick, D.L., and R.A. Weller (1993) The heat budget in the North Atlantic subtropical frontal zone. Journal of Geophysical Research, 98, 6883-6893.

Rudnick, D.L., and R.A. Weller (1993) Superinertial wind-driven flow in the Western North Atlantic. Journal of Physical Oceanography, 23, 2351-2359.

Stage, S. A., and R. A. Weller, 1985. The Frontal Air-Sea Interaction Experiment (FASINEX); Part I: Background and Scientific Objectives. Bulletin of the American Meteorological Society, 66, 1511-1520.

Stage, S. A. and R. A. Weller, 1986. The Frontal Air-Sea Interaction Experiment (FASINEX); Part II: Experimental Plan. Bulletin of the American Meteorological Society, 67, 16-20.

Weller, R.A., D.L. Rudnick, N.J. Pennington, R.P. Trask, and J.R. Valdes,1990a. Measuring upper ocean variability from an array of surface moorings in the subtropical convergence zone. Journal of Atmospheric and Oceanic Technology, 7: 68-84.

Weller, R.A., D.L. Rudnick, R.E. Payne, J.P. Dean, N.J. Pennington, and R.P. Trask, 1990b. Measuring near-surface meteorology over the ocean from an array of surface moorings in the subtropical convergence zone. Journal of Atmospheric and Oceanic Technology, 7: 85-103.

Weller, R. A. and R. M. Samelson, 1991. Upper ocean variability associated with fronts. In: Ocean Variability and Acoustic Propagation, edited by J. Potter and A. Warn-Varnas, Kluwer Academic Publishers, pp 463 - 478.

Weller, R. A., 1991. Overview of the Frontal Air-Sea Interaction Experiment (FASINEX): A study of air-sea interaction in a region of strong oceanic temperature gradients. Journal of Geophysical Research, 96(C5), 8501-8516.

Weller, R.A., D.L. Rudnick, C.C. Eriksen, K.L. Polzin, N.S. Oakey, J.W. Toole, R.W. Schmitt and R.T. Pollard (1991) Forced ocean response during the Frontal Air-Sea Interaction Experiment (FASINEX). Journal of Geophysical Research, 96: 8611-8638.

Weller, R. A., D. L. Rudnick, and N. J. Brink, 1994. Meteorological variability and air-sea fluxes at a closely spaced array of surface moorings, Journal of Geophysical Research, submitted.

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Department of Physical Oceanography

Woods Hole, MA 02543

June 10, 1994

Program Manager, Code 3223
Small Scale Physical Oceanography
Office of Naval Research
Ballston Towers One
Arlington, VA 22217-5000

Re: Final Report for W.H.O.I. Subcontract #SC-38291 to ONR Grant No. N00014-90-J-1470, *The Role of Horizontal Variability in Air-Sea Interaction*

Dear Sir:

The Frontal Air-Sea Interaction Experiment (FASINEX) took place in 1986 in the eastern North Atlantic. The goal was to observe air-sea interaction in the subtropical convergence zone, a region where horizontal gradients were expected to be large. This subcontract provided funds to complete the scientific analysis of this data.

The analysis has proceeded from calibration of the instruments, through a general description of the observations, to examinations of particular physical balances. Two papers were published detailing the techniques used to measure both atmospheric and oceanic variables. A special issue of the Journal of Geophysical Research appeared in May 1991 including eight papers about FASINEX. I was a coauthor on two of these papers, and I was the guest editor of a hard-bound reprint volume. A paper on the heat budget of the upper ocean during FASINEX has been submitted. Two manuscripts are in preparations: one on superinertial wind-driven currents, and a second on near-surface meteorological variability.

Robert Weller has been a collaborator on all the work described above. I would like to thank him for allowing me to participate in this effort.

Publications

Weller, Robert A., Daniel L. Rudnick, Nancy J. Pennington, Richard P. Trask and James R. Valdes, 1990. Measuring upper ocean variability from an array of surface moorings in the subtropical convergence zone. *Journal of Atmospheric and Oceanic Technology*, 7(1), 68–84.

Weller, Robert A., Daniel L. Rudnick, Richard E. Payne, Jerome P. Dean, Nancy J. Pennington and Richard P. Trask, 1990. Measuring near-surface meteorology over

the ocean from an array of surface moorings in the subtropical convergence zone. *Journal of Atmospheric and Oceanic Technology*, **7**(1), 85–103.

Eriksen, Charles C., Robert A. Weller, Daniel L. Rudnick, R. T. Pollard and Lloyd A. Regier, 1991. Ocean frontal variability in the Frontal Air-Sea Interaction Experiment. *Journal of Geophysical Research*, **96**(C5), 8569–8591.

Weller, R. A., D. L. Rudnick, C. C. Eriksen, K. L. Polzin, N. S. Oakey, J. M. Toole, R. W. Schmitt and R. T. Pollard, 1991. Forced ocean response during the Frontal Air–Sea Interaction Experiment. *Journal of Geophysical Research*, **96**(C5), 8611–8638.

Rudnick, Daniel L., and Robert A. Weller, 1993. The heat budget in the North Atlantic Subtropical Frontal Zone. *Journal of Geophysical Research*, **98**(C4), 6883–6893.

Rudnick, Daniel L., and Robert A. Weller, 1993. Super-inertial and near-inertial wind-driven flow. *Journal of Physical Oceanography*, **23**(11), 2351–3708.

Weller, R.A., D.L. Rudnick, and N.J. Brink, 1994. Meteorological variability and air-sea fluxes at a closely spaced array of surface moorings. Journal of Geophysical Research, submitted.

Edited Volume

Rudnick, D.L., Guest Editor, 1991. Results from the Frontal Air-Sea Interaction Experiment (FASINEX). From the Journal of Geophysical Research. Published by the American Geophysical Union.

Sincerely yours,

Daniel L. Rudnick (me)

Daniel L. Rudnick
Principal Investigator of Subcontract

cc:	Scientific Officer, Code 3223SS	(3)
	Mr. Tanner, ONR Resident Rep.	(1)
	Director, NRL, Code 2627	(1)
	Defense Tech. Information Center	(4)